0038-075C/97/1622-140–147$03.00/0
Soil Science

February 1997
Vol. 162, No. 2
Printed in U.S.A.

CROP ROTATION AND TILLAGE EFFECTS ON ORGANIC CARBON SEQUESTRATION IN THE SEMIARID SOUTHERN GREAT PLAINS

K. N. Potter[1], O. R. Jones[2], H. A. Torbert[1], and P. W. Unger[2]

Limited information is available regarding soil organic carbon (SOC) distribution and the total amounts that occur in dryland cropping situations in semiarid regions. We determined crop rotation, tillage, and fertilizer effects on SOC distribution and mass in the semiarid southern Great Plains. A cropping system study was conducted for 10-years at Bushland, TX, to compare no-till and stubblemulch management on four dryland cropping systems: continuous wheat (CW) (*Triticum aestivum* L.); continuous grain sorghum (CS) (*Sorghum bicolor* [L.] Moench.); wheat/fallow/sorghum/fallow (WSF); and wheat/fallow (WF). Fertilizer (45 kg N ha^{-1}) was added at crop planting to main plots. Subplots within each tillage and cropping treatment combination received no fertilizer. Ten years after treatment initiation, soil cores were taken incrementally to a 65-cm depth and subdivided for bulk density and SOC determination. The no-till treatments resulted in significant differences in SOC distribution in the soil profile compared with stubblemulch tillage in all four crop rotations, although differences were largest in the continuous cropping systems. Continuous wheat averaged 1.71% SOC in the surface 2 cm of soil compared with 1.02% SOC with stubblemulch tillage. Continuous sorghum averaged 1.54% SOC in the surface 2 cm of soil in no-till compared with 0.97% SOC with stubblemulch tillage. Total SOC content in the surface 20 cm was increased 5.6 t C ha^{-1} in the CW no-till treatment and 2.8 t C ha^{-1} in the CS no-till treatment compared with the stubblemulch treatment. Differences were not significantly different between tillage treatments in the WF and WSF systems. No-till management with continuous crops sequestered carbon in comparison to stubblemulch management on the southern Great Plains. Fallow limits carbon accumulation.

CONSERVATION tillage effects on soil organic carbon (SOC) distribution have been well documented although most of the studies have been conducted in humid or subhumid regions (Dick 1983; Blevins et al. 1983; Eghball et al. 1994). Comparisons have often been made between no-tillage and some form of plowing with continuous cropping. Information is limited regarding changes in SOC distribution for a dryland cropping system that includes fallow in semiarid regions. Unger (1991) and Christensen et al. (1994) demonstrated that distribution of SOC and plant nutrients changed with no-till management. No-till resulted in increased SOC concentration near the surface even when comparing no-till with stubblemulch tillage, which does not invert the soil. Nitrogen and phosphorus concentrations near the surface are increased with no-till management (Potter and Chichester 1993).

Total organic carbon mass in soils in semiarid regions with different management practices is not well documented. Recent investigations of carbon sequestration (using soils as a storehouse for atmospheric carbon) question whether total organic carbon in the soil has been increased or if the distribution of SOC has simply been altered by soil management (Kern and Johnson 1993). Tillage mixes SOC in the surface layers, which alters the distribution and may increase decomposition. Tillage also modifies soil bulk density so

[1] USDA-Agricultural Research Service, Temple, TX.

[2] USDA-Agricultural Research Service, Bushland, TX.

Address correspondence to Kenneth N. Potter, USDA-ARS, 808 East Blackland Rd., Temple, TX 76502. E-mail: potter@brcsun0.tamu.edu

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Received March 28, 1996; accepted Oct. 7, 1996.

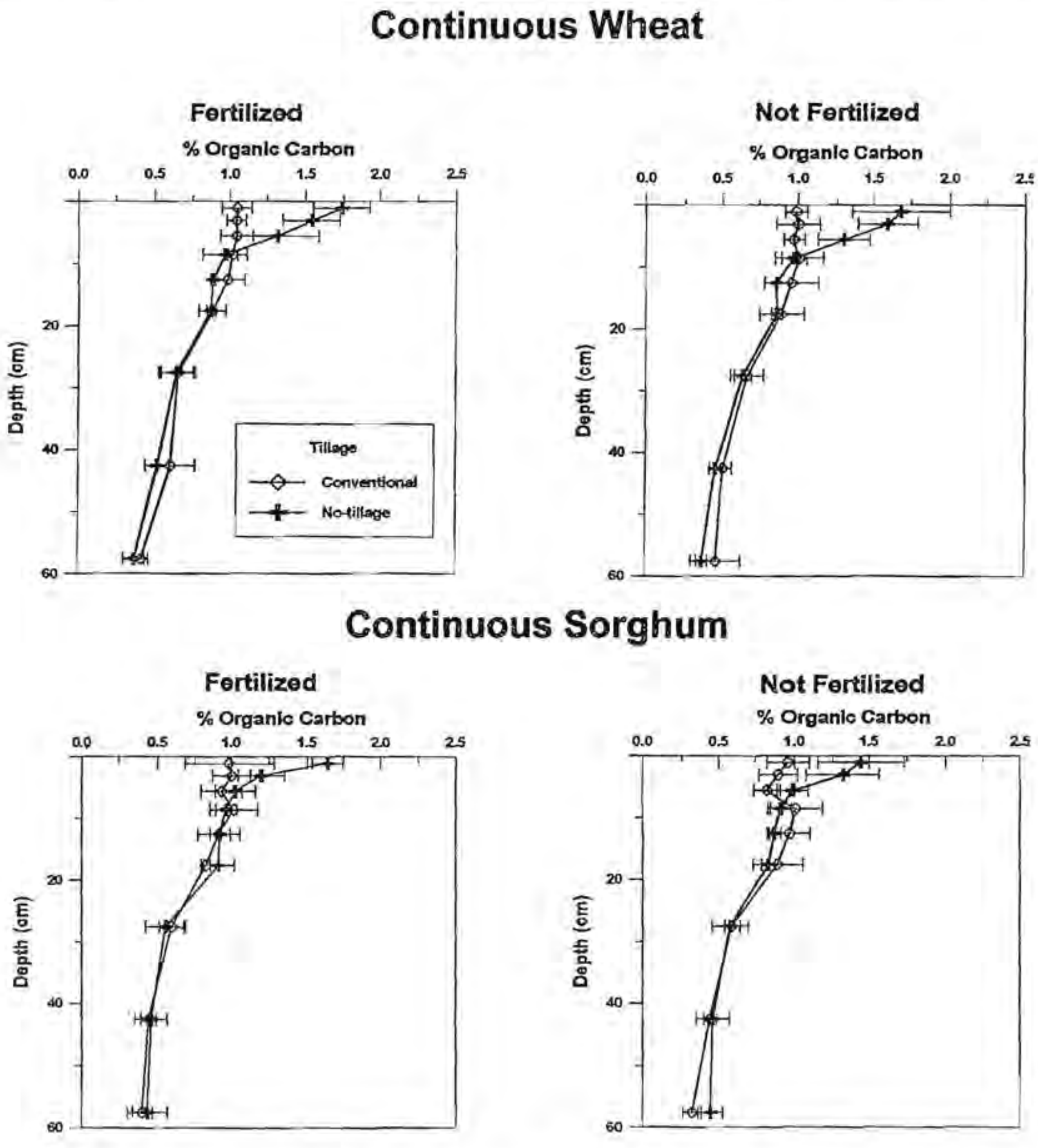

Fig. 1. Tillage and fertilizer treatment effects on organic carbon concentration profiles for Pullman clay loam at Bushland, TX, for continuous sorghum and continuous wheat (one crop each year). Error bars represent ± one standard deviation.

that similar SOC concentration information may not mean similar total SOC mass in the soil profile.

Our objectives were to determine crop rotation, tillage, and fertilization effects on soil organic carbon distribution and mass with limited carbon inputs in the semiarid southern Great Plains.

METHODS

Site and Treatment Information

Crop rotation and tillage trials have been conducted for 10 years near Bushland, TX, on a Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll). Sand, silt, and clay contents for the soil surface averaged 21.8%, 50.0%, and 28.2%, re-

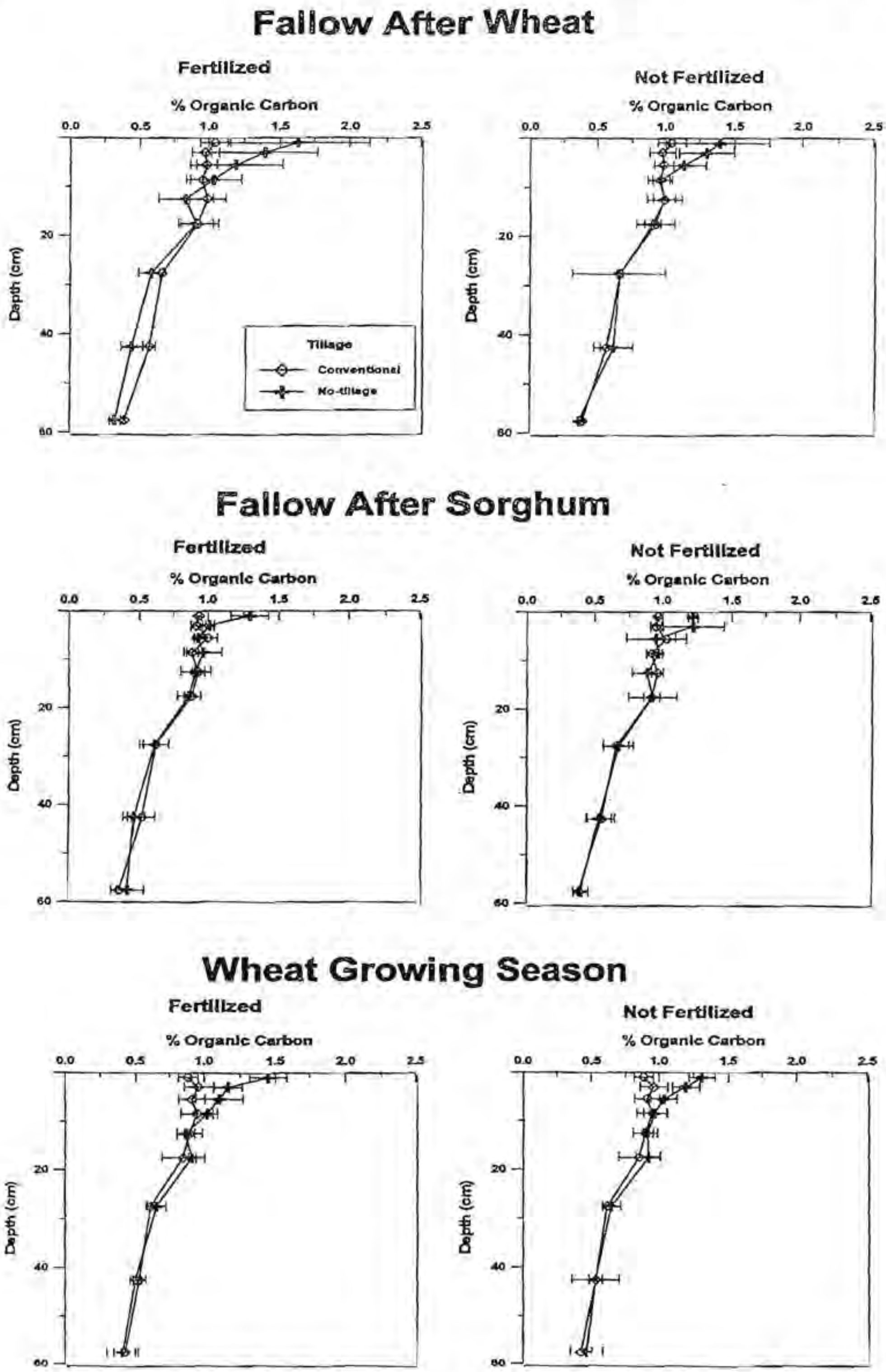

Fig. 2. Tillage and fertilizer treatment effects on organic carbon concentration profiles for the wheat/fallow/sorghum/fallow crop rotation (two crops in 3 years). Error bars represent ± one standard deviation.

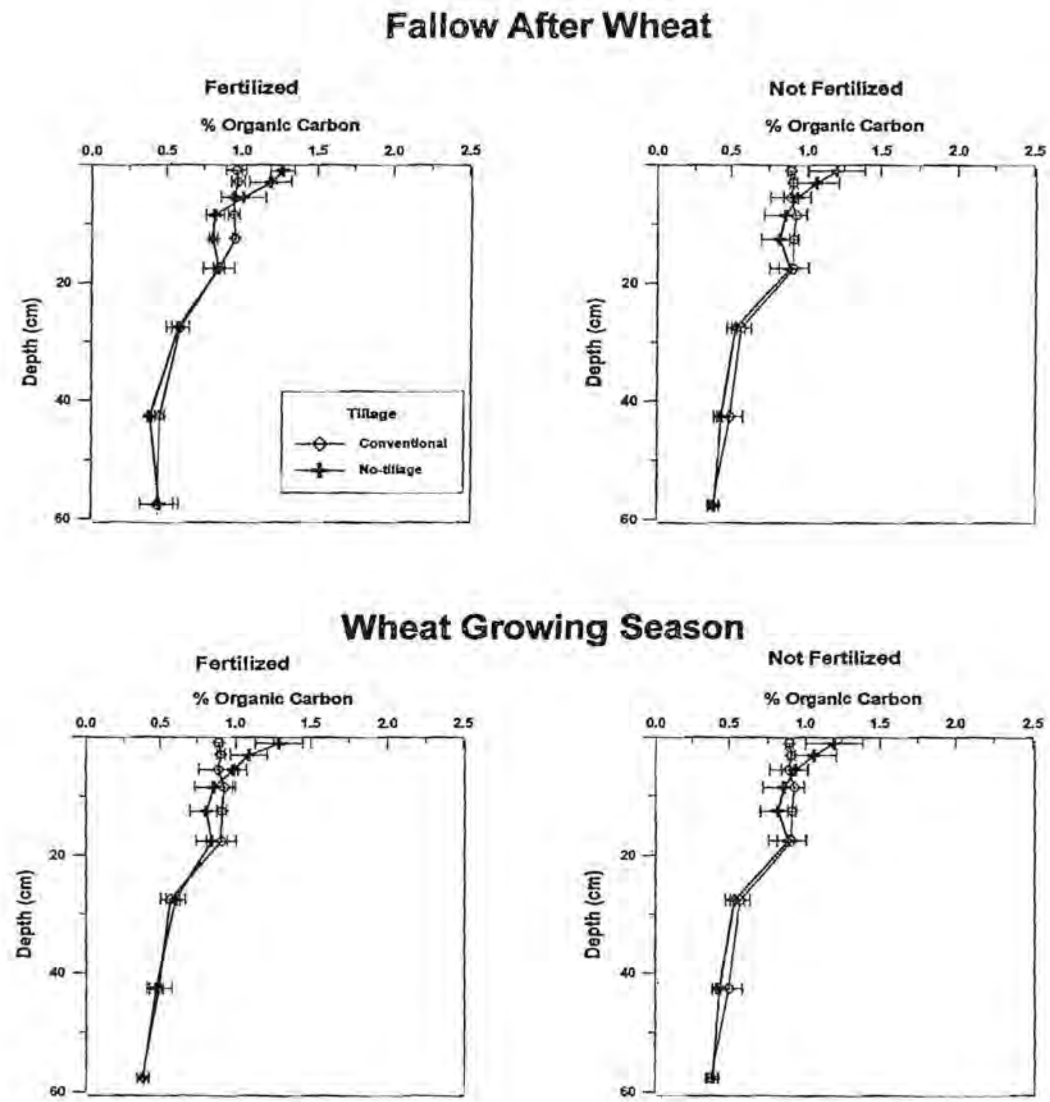

Fig. 3. Tillage and fertilizer treatment effects on organic carbon concentration profiles for the wheat/fallow crop rotation (one crop in 2 years). Error bars represent ± one standard deviation.

spectively. Mean annual rainfall at Bushland is 473 mm, and mean annual temperature is 14°C. Average 0.5-year (April through September) evaporation from a 1.2-m class A pan is 1770 mm. The frost-free growing season is 181 days and msl elevation is 1170 m.

Four crop rotations were evaluated in the study: continuous wheat (CW), continuous grain sorghum (CS), wheat/fallow (WF) (one crop every 2 years), and wheat/fallow/sorghum/fallow (WSF) (2 crops every 3 years). See Jones and Popham (1997) for more discussion of these crop rotations. All crop phases for each rotation were in place each year. Two tillage treatments were evaluated: stubblemulch tillage (Conv), and no-tillage with chemical weed control (No-till). Fertilizer treatments were (i) fertilized (45 kg N ha^{-1} at crop planting) and (ii) no-fertilizer applied.

The study was designed as a randomized complete block, with tillage and crop rotation as the main blocks and fertilizer rate as a split plot treatment with three replications. Main plots were 9 m wide and 160 m long, and unfertilized subplots were 9 m wide and 15 m long. Other

TABLE 1

Mean bulk density (Mg m^{-3}) for the Pullman clay loam for two tillage systems and four crop rotations

Depth (cm)	Tillage method	
	Stubblemulch	No-till
	Continuous Sorghum	
0 - 4	1.43 ± 0.19†	1.50 ± 0.21
4 - 10	1.47 ± 0.12	1.51 ± 0.09
10 - 20	1.56 ± 0.11	1.53 ± 0.08
20 - 35	1.66 ± 0.08	1.65 ± 0.04
35 - 50	1.70 ± 0.04	1.66 ± 0.04
50 - 65	1.78 ± 0.08	1.72 ± 0.04
	Continuous Wheat	
0 - 4	1.38 ± 0.22	1.51 ± 0.13
4 - 10	1.31 ± 0.11	1.56 ± 0.15
10 - 20	1.45 ± 0.11	1.39 ± 0.09
20 - 35	1.60 ± 0.12	1.52 ± 0.11
35 - 50	1.65 ± 0.05	1.64 ± 0.07
50 - 65	1.71 ± 0.03	1.68 ± 0.03
	Wheat/Fallow	
0 - 4	1.60 ± 0.16	1.60 ± 0.20
4 - 10	1.27 ± 0.09	1.64 ± 0.20
10 - 20	1.48 ± 0.11	1.46 ± 0.19
20 - 35	1.66 ± 0.07	1.57 ± 0.10
35 - 50	1.69 ± 0.04	1.65 ± 0.09
50 - 65	1.71 ± 0.09	1.72 ± 0.07
	Wheat/Fallow/Sorghum/Fallow	
0 - 4	1.46 ± 0.15	1.41 ± 0.18
4 - 10	1.34 ± 0.14	1.56 ± 0.16
10 - 20	1.45 ± 0.10	1.45 ± 0.10
20 - 35	1.64 ± 0.08	1.61 ± 0.06
35 - 50	1.64 ± 0.09	1.67 ± 0.06
50 - 65	1.75 ± 0.07	1.70 ± 0.06

†Mean ± standard deviation, n = 3.

management information has been presented in Jones and Popham (1997). Aboveground biomass and yield component data were obtained from two 2-m^2-hand harvested samples taken from each plot at harvest. Grain yields were obtained by combine harvesting the entire plot. Harvest index was calculated from the hand-harvest yield and aboveground biomass samples and was used to estimate the total plot aboveground biomass from the combine grain yield.

In March 1994, one soil core was taken from each plot to a depth of 20 cm for organic carbon determination. An additional sample (one core $plot^{-1}$) was taken in May 1994 to a depth of 65 cm for bulk density determination by the core method (Blake and Hartge 1986). Soil from the bulk density samples in depth increments below 20 cm were also analyzed for organic carbon content. SOC sampling from wheat plots occurred during the wheat growing season for the continuous wheat, wheat/fallow, and wheat/fallow/sorghum/fallow rotations. For other phases of the wheat/fallow/sorghum/fallow rotation, SOC sampling occurred during the fallow after wheat (referred to as the fallow phase of the WSF rotation) and fallow after sorghum (referred to as the sorghum phase of the WSF rotation). Soil cores were subdivided for SOC and bulk density determinations. Sample increments for the near surface SOC determinations (March 1994 sampling) were 0–2, 2–4, 4–7, 7–10, 10–15, and 15–20 cm. Increments for the bulk density samples (May 1994 sampling) were 0–4, 4–10, 10–20, 20–35, 35–50, and 50–65 cm.

Sample Analysis and Statistical Tests

Soil samples were analyzed for soil organic carbon with a Leco CR12 Carbon Determinator (LECO Corp., Augusta, GA) using the combustion method of Chichester and Chaison (1992). Total organic carbon was integrated over selected sampling depths within a plot. Data were analyzed with analysis of variance. Protected least significant difference tests were used to separate means at a significance level of $P < 0.10$.

RESULTS AND DISCUSSION

SOC Concentration

Soil organic carbon concentration profiles for the crop rotations, tillage systems and fertilizer

TABLE 2

Analysis of variance of tillage and fertilization effects on the total organic carbon content (0 to 20 cm) of a Pullman clay loam four crop rotations

	CW	CS	W/F† W	W/F† F	W/S/F W	W/S/F S	W/S/F F
	P > F						
Till	0.002	0.07	0.41	0.17	0.22	0.11	0.11
Fert	0.28	0.91	0.44	0.94	0.54	0.56	0.49
TxF	0.86	0.69	0.36	0.88	0.41	0.83	0.75

†Rotation and crop phases are labeled as Wheat/Fallow (W/F), Wheat/Fallow/Sorghum/Fallow (W/S/F), Continuous Wheat (CW), and Continuous Sorghum (CS).

TABLE 3
Mean total soil organic carbon mass in the surface (0 to 20 cm) of a Pullman clay loam soil as influenced by rotation and crop phase

Rotation-crop	Stubblemulch	No-till
	t C ha^{-1} 20 cm^{-1}	
CS-Sorghum	27.8a†	30.6b
CW-Wheat	27.0a	32.6b
W/S/F-Fallow	27.0a	30.6a
W/S/F-Sorghum	26.8a	29.0a
W/S/F-Wheat	26.6a	29.8a
W/F-Fallow	26.6a	28.6a
W/F-Wheat	25.4a	28.2a

†Values within a row followed by different letters are significantly different at the P=0.10 level.

treatments are shown in Figs. 1 to 3. Differences in SOC concentration between tillage systems were generally limited to the surface 7 cm. No-till had a greater SOC concentration at the surface than did stubblemulch tillage, but SOC quickly decreased with depth. Below 7 cm, significant differences between tillage treatments were not observed. The greatest increase in surface SOC with no-till occurred with the continuous cropping systems. Continuous wheat averaged 1.71% in the surface 2 cm of soil compared with 1.02% with stubblemulch tillage. Continuous sorghum averaged 1.54% SOC in no-till compared with 0.97% SOC with stubblemulch tillage. Inclusion of fallow in the crop rotation resulted in lower SOC concentrations at the surface than occurred with continuous cropping. Fertilization did not affect the SOC concentration significantly. These results agree closely with those of Unger (1991), but his results were limited to the WSF crop rotation after sorghum harvest. Other researchers have also reported that management effects on soil carbon concentration are generally limited to the near surface horizons (Havlin et al. 1990; Dick 1983).

Bulk Density

Bulk density values were lowest near the surface and increased in value with depth (Table 1). Tillage treatments had little effect on bulk density at the time of measurement except that stubblemulch tillage resulted in lower mean bulk density values in the 4 to 10-cm depth increments compared with no-till in the CW and WF crop rotations.

SOC Content and Accumulation

Calculations of total SOC content were made only for the surface 20 cm because total SOC content calculations are dependent on the concentration of SOC and soil bulk density. Differences in both bulk density and SOC concentration below 20 cm were small. Tillage resulted in significant differences in total SOC content in the surface 20 cm with continuous cropping (Table 2). Rotation crop phase had an effect in the WSF rotation as the sorghum and fallow phases had a trend toward increased SOC with no-till, but the wheat phase did not. Tillage was not a significant variable in the WF crop rotation. Fertilization had no effect on total SOC content (Table 2). Tillage by fertilizer treatment interaction was not significant.

Because fertilization was not a significant variable, total SOC content was summed over fertilizer treatments (Table 3). Total SOC content in stubblemulch tillage plots was not significantly different among rotations and averaged 26.6 t C ha^{-1} in the surface 20-cm. No-till always resulted in greater SOC content compared with stubblemulch tillage within a rotation, although the differences were statistically significant only in the continuous cropping systems. With no-till, CW resulted in significantly greater SOC content than the WSF and WF rotations, and CS resulted in a significantly greater SOC content than the WF system.

Differences in SOC accumulation between tillage systems have been explained as resulting from different amounts of breakup of crop residues and mixing with soil. The resulting exposure of residues to water and oxygen resulted in more rapid microbial decomposition of residues (Doran and Smith 1987).

TABLE 4
Mean annualized aboveground biomass remaining after harvest

	CS	CW	WF	WSF
		t ha^{-1} yr^{-1}		
Stubblemulch	4.5 ± 0.2†	2.2 ± 0.2	1.8 ± 0.1	2.5 ± 0.9
No-till	4.2 ± 0.2	2.8 ± 0.1	1.9 ± 0.1	3.1 ± 0.5

†Mean ± standard deviation, n=3.

Soil organic carbon accumulation is also affected by the amount of crop residue returned to the soil and by differences in the quality of the residues being returned. Several studies have related SOC to the amount of residue returned to the soil (Havlin et al. 1990; Larson et al. 1972). In our study, grain sorghum resulted in larger amounts of aboveground biomass being returned to the soil than did the rotations that included only wheat (Table 4). The WF and WSF rotations produced more biomass on a per crop basis than the continuous cropping systems, but when the fallow period is included, mean annual biomass inputs are reduced compared with continuous cropping. Also, except for the CS rotation, no-till increased mean annual biomass inputs for all rotations because of reduced evaporation and increased soil water storage (Jones and Popham 1996). Despite the larger amounts of aboveground residue returned to the soil with the CS rotation, the CW rotation resulted in greater SOC content (Table 3). This result indicates that the decomposition rate of plant residue was slower over the long term for the wheat compared with the grain sorghum. The decomposition rate of plant residue is dependent on several factors, including age, size, lignin content, and the C/N ratio of the residue (Parr and Papendick 1978; Ghidey and Alberts 1993). Changes in the plant structure, even within a plant species such as wheat, have been shown to alter the rate of microbial decomposition (Ball 1992). Slower decomposition of wheat compared with grain sorghum may have been the result of differences in the residue nitrogen content. Wheat straw typically averages 0.667% N, and grain sorghum stover averages 1.083% N (Hansen 1990). The lower nitrogen content of the wheat residue may result in a N limitation to microbial decomposition resulting in slower decomposition compared to grain sorghum.

The rate of change in SOC content attributable to no-till management was estimated by determining the difference between SOC content values for no-till and stubblemulch tillage management systems, assuming that the rate of change for tilled plots is negligible and dividing by the number of years of continuous management. Similar assumptions have been used to estimate the effect of no-till for a range of locations (Reicosky et al. 1995). Because each phase of a crop rotation contributes to the SOC content, mean SOC content values over all phases within a rotation were determined for each crop rotation. With continuous cropping, no-till wheat resulted in a more rapid accumulation of SOC than no-till sorghum. Inclusion of fallow in the crop rotation, as in the WSF rotation and the WF rotation, reduced the average rate of carbon sequestration with no-till compared with the CW crop rotation (Fig. 4).

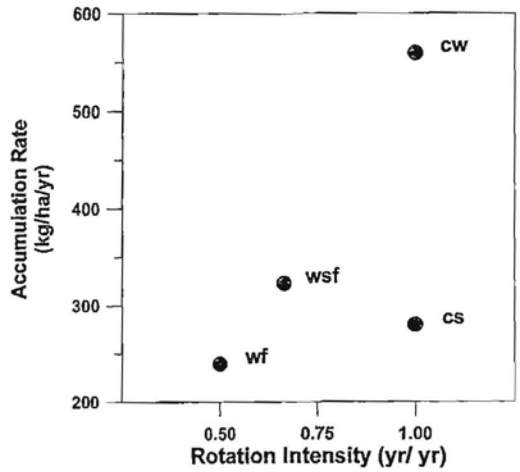

Fig. 4. Mean organic carbon accumulation rates for no-till for selected levels of rotation cropping intensity (i.e., crop years/calendar year).

SUMMARY

Organic carbon distribution in the surface 7 cm of soil was altered 10 years of no-till management when compared with stubblemulch management for four crop rotations on the southern Great Plains. Despite the change in organic carbon distribution, total soil organic carbon content was increased only in continuous cropping systems, with the greatest increase occurring with continuous wheat. Fallow, which is commonly used in this region to increase soil water storage, limited the sequestration of organic carbon in the Pullman soil.

ACKNOWLEDGMENT

The authors thank Mr. Shawn Rowan for his diligence in sample organization and analysis.

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